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WOOL—ITS STRUCTURE and STRENGTH.

—BY—

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WOOL—ITS STRUCTURE AND STRENGTH.

By Wm. McMurtrie, E. M., Ph. D., *Professor of Chemistry.*

The study of the structure of the wool fibre, its several physical properties, its length, its fineness, its strength and elasticity, and the relation of all these properties to the conditions of breeding, feeding and management, as well as the influence of the latter upon the quantity of wool that may be produced from any given flock, are subjects that should engage the serious attention of every intelligent wool-grower, and they are of as great importance and as worthy of his consideration as the study of plant nutrition and the several economic sources of plant food are to the successful grain-grower or the horticulturist. But it is largely true that in this country the quantity of wool that may be produced has been the most favored consideration, and among growers of fine wools and breeders of marino sheep, large carcasses, heavier fleeces, increased yolk, complete covering of the body, and in some cases numerous folds of the skin have been the more important points to be attained. With these secured, all else that might be desired is expected to come, and indeed without the knowledge of the breeder much does come. Of course the breeders of fine wool desire that the wool shall be fine, but beyond this quality little enters into their estimate of the value of the staple. All the qualities named have their place and value, but it still remains most important at this stage of the advance of the great wool-growing industry to inquire into the influence of all these important conditions upon the quality of the staple produced or the physical properties of the fibre, on which the manufacturer must wholly depend in the choice of his stock.

It has been our good fortune to make a detailed study of the physical properties already named as exhibited in the staple from various sources, and the results of this study have been embodied in a voluminous report to the Commissioner of Agricu ture. It is believed that some brief abstracts from these results will be of interest and value for presentation here, because the work has largely been carried on at the University of Illinois.

It will of course be impossible at this time to present even a limited outline of the methods that were followed in this study, or to give any extended description of the character of the examina-

tions made further than may be needed to make the results clearly understood. For the greater data we can only refer to the detailed report now in press at the Government Printing Office.

STRUCTURE OF WOOL.

If we take a tuft of woof in the hand we find it composed of a bundle of fibres similar in many respects to hairs, yet differing from these latters in several important particulars. If we separate from the tuft a single fibre and draw it between the fingers, we find that in one direction it draws very much more readily than in the other. Pull it with sufficient strain and before it will break it will stretch from one-third to one-half its length, and thus prove to be more or less elastic. If we cleanse a tuft of fibres, and by any convenient means mix the fibres so that they become more or less interwoven, and then pound or otherwise bring the fibres into close contact with each other, we find that the mass will soon become closely matted to a degree dependent upon the extent of manipulation, and the breed from which the wool was taken. We say it has felted. If we stretch a small bundle of fibres and then snap it while under tension, we find it will give a more or less clear ring, according to its quality. By its appearance and feel we determine whether it be fine or coarse.

All these means enable those engaged in the woolen industry to arrive at their appreciation of the value of any given lot of wool. The minute structure of the fibre has as a rule little value for, or at least has received but little of attention from, the practical wool-grower, buyer, or manufacturer. And very naturally; for neither education, habits of work nor absolute necessity have intervened to lead them to such study.

For proper examination and study the fibre must be suitably prepared and "mounted" upon a glass slip ordinarily used with the microscope, and because of the "crimp' common to it, the fibre should be subjected to sufficient tension to remove the crimp and bring the entire portion of it within the plane of the glass slip, and thus render it possible to bring a larger length within the focus at the same time, or to make examination and comparison of several fibres side by side simultaneously. For this purpose we have made use of a very simple device, which consists of supporting the slip at each end by thick blocks. Drawing a fibre at random from the tuft, which has previously been cleansed with ether, a small weight, such as an iron nail, is attached to each end, and the fibre then laid across the slip. When several fibres have been thus prepared and laid across, they are brought together as closely as possible, by means of a needle. Then a drop of a mixture of glycerine and alcohol is placed upon the fibres thus arranged, a cover glass is placed over the whole, when it soon becomes ready for examination and study. Other media than the mixture of alcohol and glycerine may be used, but we have found the refractive power of this to be about what is needed to secure the best development of the several details of minute structure, so that in our late work we have used it to the exclusion of all others.

To diminish the transparency of the fibre it is often desirable to submit it to the action of analine or other dyes. I have used with very great advantage a weak solution of silver nitrate in ammonia. The wool is digested in this solution a few minutes, then taken out, washed, dried, and gently warmed for some time. It quickly turns drab, and renders the fibre much more opaque. But in the use of this substance great care must be observed not to make it too strong, because then the fibres may be made too black. Upon the whole, however, I think that, with suitable mounting media, staining may be avoided.

If, now, when the wool is thus prepared and mounted for examination, it be brought within the focus of a good microscope, its external characteristics become manifest. It is presented to the vision as a broad band with nearly parallel edges, the latter sometimes provided with slight projections, often erroneously called serrations, while the surface is covered transversely with irregular lines. And we find, too, that some of these lines are connected with the serrations seen at the edge of the image. The fibre is generally transparent in white wools, opaque in colored wools, while some of the long wools exhibit through the middle of the image a portion much less transparent than the remainder, indicating a difference in the structure in that portion. It is important to observe in this connection that a perfectly neutral substance should be used for the mounting medium or the fibre will become distorted and in time disintegrated.

But if the fibre be placed for examination in some tolerably strong caustic alkali or acid the fibre swells and the transverse lines already mentioned become more marked, ultimately showing that they represent the edges of scale-like appendages or coverings which, by longer continued action and with the aid of heat, may be completely separated. With care in manipulation it will appear that these scales, which are infinitely thin, are attached to an equally thin membrane or skin surrounding the fibre. If sulphuric acid (oil of vitriol), not too strong, be used to produce the disintegration, and during the operation slight abrasion be applied by pressure upon the cover glass, and careful movement, this skin with the scales attached will slip away from the body of the fibre and may be studied separately. It is found upon all wools, but may be obtained separately more readily from the down wools than from the others.

The scales upon the wools of different breeds appear to have a more or less characteristic form, and it has been believed that the forms manifested could be made a basis of differentiation of breeds. It appears, however, that more study in this line will be needed, and that even if it can be applied, long practice in examination will be needed to detect impurities of blood in this way. At the same time there is no doubt of the value of the indications sometimes afforded.

In the long wools the scales are more or less angular, the edges broken, and the general form irregular, especially in the coarser fibres. In the short and medium wools greater regularity prevails; the edges are more definitely curved and have more tendency to extend around the fibre, while at the same time they are more

nearly parallel. With this regard the long wools differ to a marked extent from the down and merino wools, the latter really being very similar. In crosses, or in merinos tainted with long wool blood, these peculiarities in the form of the scales are often apparent, and, as already intimated, sometimes significant. So strongly have we been impressed by this fact that we once took occasion (?) the exclusion from a breeding flock of animals in whose wool they occurred, although the record of the animals and their pedigree could furnish no intimation of taint of impure blood. We earnestly believe that this offers a valuable field for study and investigation, and that such study should be vigorously prosecuted in the interest of breeders of fine wooled sheep.

We may not dwell at greater length here upon these external characteristics of the fibre, and may pass to a consideration of the internal structure. We have already said that if the fibre be subjected to the action of tolerably strong acid it swells, the edges of the adherent scales rise, the scaly membrane may be removed, and after longer continued action we find that the body of the fibre suffers disintegration. At first indistinct lines or striations appear throughout the length of the fibre. After some time slight abrasion reduces it, and we see it break down and separate into what are apparently elongated cells. At the end of the fibre, or rather at the end of the portion under examination, these first partially separate and sway to and fro in the supporting liquid, and finally become detached and float away. When thus separated they appear spindle shaped, that is, pointed at both ends and larger in the middle portion, while at the same time they are more or less flattened. In the natural condition of the fibre they overlap each other, and doubtless communicate the property of elasticity so peculiar to wool. The body of the fibre consisting of these elongated cells we have termed the *fibro cellular* portion or tissue.

In the study of the merino wools, and of most of the pure down wools, the fibres are all very transparent, especially when supported or mounted in the volatile oils or the balsams. But under the same circumstances we find that through the central portion of the long wool fibres there runs a more opaque portion. If a fibre showing this peculiarity be treated on the glass slide for some time with sulphuric acid or a concentrated alkali, the former being the safest, it will break down, the scaly cuticle and the fibro cellular tissue will be separated and finally dissolved, while the cells of granular matter will remain behind. This matter differs materially from the remainder of the fibre, and its presence in the fibre is believed to impair its strength. It may be partially removed at least from the end by such solvents as turpentine and the balsams, and doubtless by some others, especially the essential oils. The fibro cellular tissue is not thus soluble. When the granular matter is thus dissolved away there remains a net work of cell walls which enclosed it.

The granular matter is found particularly in those wools that are very white when cleaned, and lacking in lustre, and it is especially common to the wool of the Cotswold breed. It is not always confined to the central portion of the fibre, but may be distributed throughout the body of the fibro cellular tissue. It is not common to the pure downs and merino wools, though it is sometimes found

in the former. In the wool of the Oxforddown it is especially abundant. Its general absence in the best bred and undoubtedly purest strains of Merino wools would seem to indicate that its presedce in wools of this breed may be accepted as proof of contamination with long wool blood at some period of the pedigree of the animal upon which it was produced. This is another relation that should be further carefully studied.

The cross-section of the fibre also constitutes an interesting subject for study. For this purpose the fibre must be cut off at right angles with its longitudinal axis, in extremely thin sections, and to effect this properly the greatest care must be observed. In our own we have proceeded as follows: The fibre is first supported in paraffine. A tuft is drawn from the stock and carefully cleansed with ether or benzine, and then immersed in melted paraffine. To free it from all bubbles of air, etc., it is then drawn between the fingers repeatedly until the paraffine is hard. The immersion is now repeated and the tuft again drawn between the fingers. A third immersion generally proves sufficient. A hot rod is then thrust into a block of paraffine deeply enough to admit a portion of the prepared tuft; the latter set vertically within the paraffine thus melted, and held perfectly upright until the paraffine has become sufficiently hard to support it. Care must be observed that at the time of inserting the tuft the paraffine in the cavity is not hot enough to melt that surrounding the tuft. When thus prepared the block of paraffine is placed in the section-cutting instrument, of which there are very many forms, and the thinnest possible sections cut off at right angles with the tuft. The slices of paraffine supporting the sections of the fibre may then be mounted in oil for examination, or if the sections are sufficiently thin the paraffine may be dissolved away and the sections themselves mounted in any suitable medium. Sometimes, in order to make the outlines more distinct, it is desirable to steam the fibre before supporting it in the paraffine, and any of the anilines may be used for this purpose.

When we come to examine these sections with the microscope we find that they are nearly circular, showing that the fibre has a form approaching cylindrical, but they are seldom, if ever, perfectly round, and are of almost infinite variety of form. Of the wools of the several breeds, that of the Merino is probably the most regular, varying from nearly circular to elliptical.

If the sections thus cut off are submitted to the action of sulphuric acid, they soon begin to suffer disintegration, and the several parts may be separated. By this means we find, as before, that the fibre proper consists of two essential parts, the shaft of fibro-cellular tissue and the covering of scale-supporting membrane or cuticle bearing the scales. This constitutes the structure of nearly all Merino wools and many of the *pure* down wools. But we have seen that through the middle of the image of long wool there runs a more opaque portion, and this appears also, of course, in the cross-section, as an irregularly defined spot in the center of the section. The coarse wools may therefore consist of the shaft of granular matter resembling pigment, though differing in its distribution from the pigment of colored wools, the shaft or cylinder of fibro-cellular tissue, and the scaly cuticle.

We conclude, therefore, that the wool fibre is a more or less cylindrical shaft, surrounded by a scaly cuticle, or at least scales attached to each other or to a supporting membrane, and that this cylinder in its normal condition is of nearly uniform diameter throughout its length. Very often, however, we find considerable variation with this latter regard. Sometimes we find the fibres contracted at certain parts of the shaft, often gradually, but quite as frequently suddenly, so that the contraction presents the form of a notch in the side of the image as viewed through the microscope. At other times enlargements occur, so that the fibre may be almost doubled in size. The contraction is known as *atrophy* and the enlargement as *hypertrophy*. Many observations have shown that when the animals have been in perfect health through the year, and have been well fed and cared for, these forms do not occur, and that these forms may be accepted as indications of the condition of health of such animals. They impair that quality known as evenness, and then their production should therefore be avoided as far as possible by close attention to the food and shelter provided for the flocks.

Neither wool-growers nor manufacturers have any difficulty in fixing a general classification of wools. The differences are sufficiently distinct to separate the *long* from the *short* wools, and the *coarse* from the *fine*. And when we examine the external minute structure of the fibre with the microscope similar differences are apparent. A practiced eye may at once distinguish between the wool of any long-wooled breed and that of the short-wooled breed; but there is greater difficulty in distinguishing between the wools of these two great classes, a difficulty especially marked when we compare the several classes of fine wools established by the commercial graders. All the long wools, the Cotswold, Lincoln and Leicester, have very much the same external structure. In the same way the *pure* downs and marinos approximate each other so that in the latter case the main difference, perhaps, is found in the fineness. If in the practice of breeding we produce a cross between the long and the short wooled breeds, the external characteristics of both appear in the progeny, and similar characteristics appear in the wool, so that those of either blood will be maintained in the wool of the descendants for several generations, and are more indelibly impressed upon the Merino race by crosses with the long-wooled races than with any others. In many cases, therefore, microscopic study of the fibre becomes more valuable in the determination of the purity of the pedigree, than any general indications can possibly be. The tendency of all animals to deterioration and to revert to the inferior stock makes such distinctions permanent. It appears to be a fact that the introduction of *pure* down blood to the Merino causes less marked differences, and these differences should have less of influence for evil than taints of long wool, still they are frequently apparent in variations in the fineness of the fibre, producing sometimes very uneven staple. We cannot further discuss this point here, but enough has been said to indicate its importance.

FINENESS OF WOOL.

In wools, as in connection with all other materials, fineness is a relative term, and it may here be fairly represented in the diameter of the fibre, if the latter be considered a cylinder, though it is never perfectly round. The German authorities have been accustomed to measure this in the diameter of the fibre by various means, using single fibres, but the favorite mode in use and recommended by the best authorities consists in measuring the breadth of a band of several fibres brought into close contact, or in the area of cross section of a bundle of fibres when pressed together. But it would seem that for one accustomed to the use of the microscope in the study of fibres, either of these mechanical means must prove defective. However closely the fibres may be brought together in this way, there must always remain interstices between them often large enough to admit additional fibres. Undoubtedly the most accurate degree of fineness must be represented in the absolute area of cross section of the individual fibre, that for a sample in the average area of a large number of individual fibres. And with the apparatus now available for making cross sections of the fibres the matter of measurement of their areas becomes one of much less difficulty than formerly. For instance for this purpose, prepare the cross sections as already described, project the image upon paper of uniform thickness, trace the outline of the section, cut out the form in the paper, following the outline, and carefully dry and weigh the piece; compare the weight of the piece thus obtained with that of another from similar paper, and of standard area, and from the data thus secured calculate the area of cross section of the fibre under measurement. This method, which it seems to us leaves nothing to be desired in the way of accuracy, is necessarily laborious and tedious. In our own work, on account of the very nearly cylindrical form of the fibre, we have considered it quite sufficient to measure the diameter of the fibre as represented in the width of image seen with a microscope of high power. The wool to be examined with this regard was mounted in a state of nature, without cleansing, in Canada balsam, and then with a microscope having a magnifying power of about 400 diameters and an eyepiece micrometer, the widths of the images measured. For each sample the following method in detail was followed: First, a small tuft was drawn at random from the sample under examination; this was placed upon the table and cut into three or more parts, according to the length of the staple. Each one of these parts was then mounted after the manner just described. Each slide supporting a part was properly labled and numbered, and three of the fibres upon it; the diameters or widths of images of thirty were carefully measured. The average of these thirty measurements were taken to represent the fineness for the part, and the average of the measurements for all the parts to represent the fineness of the sample. For the latter, therefore, from 90 to 150 measurements were always taken. In this way, as in connection with other properties, it has been our good fortune to study the wools of the leading breeds of the United States, that is to say, the Cotswold, Lincoln, Oxford-down, Southdown and Merino.

This property of fineness establishes in a general way the classification of the wools of different breeds, but of course it never enters into minute comparisons except as between wools from different animals of the Merino race. As between the four principal breeds studied, these range from finest to coarsest—Merino, Southdown, Lincoln, Cotswold. In the Merino wool, although the weight of fleece secured constitutes most frequently the important consideration and is made the subject of special prize at the fairs and shearings, fineness at the same time should and does form a no less important term of comparison. All other things being equal, the finest wool is of course the best. Conditions which modify and increase the fineness should be studied with the greatest care. In some cases it appears that it is not altogether consistent with the greatest vigor of constitution, but it does appear that it may be modified to a marked degree by breeding and by care. Selections in breeding should be made with this regard as carefully as with regard to size and form of carcass or to strength of constitution, and are as likely to afford satisfactory results.

In the American Merino the fineness will vary from 5 to 15 per centum of the average diameter of the fibre, and this variation may be ascribed to differences in the condition of the animal as regards health, nutrition, and the care it receives. Continued good health, good food, protection from the inclemencies of the weather, show their influence in the production of very even staple of the best quality, while deficiency in either respect will leave its impress upon the fibre in the way of the variations we have referred to. It is an interesting fact that the fineness of the fibre throughout its length forms a fairly good record of the condition of the animal producing it at the several stages of growth, any defection being shown in the diminished diameter of the fibre. These facts teach an important lesson that need not be expressed.

My study of wools was extended not only to the Merino wools of the present generation both of this country and Europe, but to the flocks of 1815, those of the celebrated breeders Wells and Dickinson. The results of the measurements show that the wools of the Wells and Dickinson flocks were even coarser than the long-wooled Merinos of the present decade, showing that the American system while it has increased the weight of the fleece many fold has also improved the fineness. But in the latter the variations throughout the length of the fibre show the necessity for greater care in the management of flocks. The same remark applies in comparing the American with the foreign product. Whether or not it be due to any more abrupt changes in our climate than in that of Europe, it is nevertheless a fact that while the American product is fully as fine it is not always as even throughout its length or from fibre to fibre.

German records have shown that the weight of the fleece in Merino breeds increases with advancing age until the third or fourth year, after which there is a gradual decline in the weight of the fleece. Measurements of fineness show that the fibre also grows coarser with increase in the age of the animal.

There is another condition in the American Merino that has an important influence upon the uniformity of fineness throughout the fleece, and because of the discussion it has aroused, we naturally

hesitate about approaching it. In the examinations we have made, very considerable attention was given to the fineness of the fibre upon the top of the folds in the Merino skin as compared with that produced upon smooth skin. In the former we find many fibres more or less resembling hairs, and the average of all samples show the fibre to be much coarser upon these parts than elsewhere, and often as coarse as the fibres of the ordinary coarse wools. The introduction of such wide variations in the quality of the fibre raises the question that it seems difficult for breeders to decide: Can these disadvantages be counter-balanced by increased weight of the fleece due to the wrinkles or folds? There is at any rate no question of the following facts:

1. Wool from the tops of wrinkles is much coarser than that from between them and from smooth skin.
2. The coarser fibres are about as coarse as the ordinary coarse wools.
3. The fibres are more or less heavy, are stiff and harsh, lacking in pliability, and hence undesirable in fine goods.
4. The wool upon the wrinkles is much less dense and is shorter than that upon the smooth skin.

There may be conditions of breeding, such as hardier constitution, heavier fleece, etc., that must be taken into consideration in the improvement of common flocks, but the results just described show that growers of fine wools should seriously consider the desirability of excluding from their flocks these greatly wrinkled animals.

The relation of the "crimp" of the fibre in Merino wools to their fineness has always been a subject of more or less discussion among those interested, and in the course of our examinations, having ample material, we took occasion to develop it. In the case of such sample of Merino or Southdown wool examined, the crimp was carefully determined and stated in the number per inch of length of the staple in the sample, and after the fineness had been determined, the two data were compared. Taken as a whole, the figures show that the fineness varies directly according to the closeness of the crimp, and that with this condition the fiber as a rule is much finer than in case of more open crimp; that with increase in the number of crimps per inch there is a decided decrease in the average diameter of the fibre, so that in this condition all interested in the staple have here a ready means for the general determination of its value as regards fineness.

More definitely it appears that with different crimps per inch the fineness in the Southdown and Merino wools vary about as follows:

Number of crimps per inch.	Fineness in Centimillimeters.
12	2.8 to 3.27
14	2.1 " 2.8
16	2.1 " 2.6
20	2.1 " 2.24
22	1.8 " 2.0
25	1.8 " 1.9
26	1.7
30	1.5

These relations are by no means absolute but they agree closely with the results of our determinations and measurements. It must be observed, however, that while these are the indications afforded by the averages of our results and therefore establish a general rule, they do not altogether agree with those obtained for individual samples. It frequently happens that there is no relation whatever between the fineness of the fibre and its crimp, so that a grade made upon this indication alone might be exceedingly irregular as regards this quality of fineness.

There seems also to be some relation between the density of the fleece and the fineness of the fibre. Thus in a series of samples from two sets of fleeces, the one set being much closer or more dense than the other, the following results were obtained in centimillimetres, by measurement of fineness. For the dense fleeces: Rams, 2.151; ewes, 2.119; Loose fleeces: Rams, 1.913; ewes, 1.974.

The loose fleece therefore appears to produce the finer wool. Of course these results were obtained from only a limited number of samples and can only be an indication of what may be expected from further study in the same direction, but the fact is worthy of the attention of growers of fine wools.

One other consideration relative to fineness and we must have it. This is the relation of the section of the country in which the wool is grown to this quality. In the later part of our work it was deemed desirable to apply the methods of investigation already devised to this question. To this end collections of samples of merino wool were made from as nearly as possible all the wool growing sections of the United States, the principal aim being to secured material from animals directly descended from the pure Vermont stock. The earlier work had shown that the highest degree of fineness was attained at about the age of two years, and contributors were requested to send samples from animals of this age and from as near the shoulder as possible. Twenty samples from rams and twenty samples from ewes were taken in each locality, and this number was believed to sufficiently represent the average of the entire flocks. Samples were thus secured from all the states named below, and presumably represented the best wools obtainable. The figures of the following table are averages of all the measurements taken for each State, and are represented in centimillimetres and ten thousandths of an inch:

	Centimillimetres.	Ten thousandths of an inch.
Pennsylvania	1.711	6.729
Texas	1.837	7.226
California	1.883	7.407
Illinois	1.902	7.782
Vermont	1.979	7.801
New York	2.034	8.034
Wisconsin	2.048	8.085

The variation in these figures is by no means wide and is scarcely sufficiently decided to lead to the conclusion that any influence whatever is had upon this quality by the several different sections. The differences may have been due to differences of judg-

ment in collecting the samples, or even in the part of the fleece from which the wools were secured. The variation from the average amounts to from about 5 per cent on one hand to about 11 per cent on the other.

From all our study with regard to the fineness of fibre of wools we deduce the following conclusions:

1. It is affected by breed—and with this regard the wools of the several breeds stand in the following order from coarsest to finest: 1, Oxforddown; 2, Cotswold; 3, Leicester; 4, Lincoln; 5, Hampshire; 6, Southdown; 7, Merino.

2. It is to some extent related to sex, but with this regard each breed is a law unto itself.

3. It differs from one part of the fleece to another but no general rule can be established on this point. In the majority of cases, however, the shoulder wool is finer than that from the side, which in turn is finer than that from the hip. The belly wool is almost invariably finer that that from other parts.

4. The age seems to be without marked influence in the Merino breed, but in the coarse wools the fineness seemes to decrease with increase of age, that is to say, with advancing years the fibre seems to become coarser.

5. The fibres from the tops of the wrinkles or folds is decidedly coarser and less even than that from between them and from the smooth skin, and animals with numerous and large folds in the skin should, as far as possible, be excluded from flocks devoted to the production of *fine even* wools.

6. A relation prevails between the number of crimps per inch and the fineness of fibre in Merino wool, and while this is not absolute in all cases, it may serve as a general indication of the quality in question.

7. Loose fleeces in Merino wool appear to contain finer fibres than the dense fleeces.

8. To some extent the fineness of Merino wool seems to be affected by the section in which the wool is grown, but the differences are not so marked or so distributed as to indicate that they are due to climate, or to anything more than the natural variations occurring in different lots of wool, or possibly to slightly different care in the management of the flocks.

STRENGTH AND ELASTICITY OF WOOL.

In the study of the comparative fineness of the fibre we are only upon the threshold of the work of fixing the ultimate value of the staple in all its relations, industrial and commercial. While many of the commercial grades are established upon this quality alone, manufacturers and consumers alike are interested in knowing to what extent any given lot of wool will be able to resist the wear it must be subject to in its various applications, and the power necessary to this must be found, and find expression, in the ultimate strength, or generally the strength and elasticity of the fibre as variously produced or treated.

Strength is the power to resist strain, and stretch the elongation produced by strain, limited only by rupture. Elasticity is the power

to return to original condition after elongation due to strain. Strength may therefore be represented in various ways: that is, it may be represented in units of weight necessary to rupture, or units of weight necessary to produce any stretch in percentage of original length. Elasticity may in general be fairly represented in the percentage of stretch suffered previous to rupture. But the stretch may be of two kinds. If, for instance, a fibre be submitted to strain not sufficient for rupture, it will stretch. If this strain be removed the tendency will be to return to its original length, but this return will be incomplete. The fibre will have permanently stretched, and will have *set*. The difference between the *total stretch* and this permanent stretch constitutes the elastic stretch. It is upon data of this kind, and the relation between them, that we must depend for an appreciation of the ultimate value of wool.

These data with regard to wool are obtained in the following manner: A dynamometer is constructed in which a wheel is delicately mounted to avoid friction as far as possible by pointing the extremities of its axle, and inserting these in conical boxes, so that the wheel is really supported upon points. Fixed to the axle is a pendulum, or lever, weighted at its lower extremity. Over the periphery of the wheel passes a light chain, which supports at one end a screw clamp. Underneath this clamp, and in the same vertical plane, is a second clamp fixed to a rod, which may be moved up and down by a screw motion at the base of the instrument. Attached to the clamp is a horizontal indicator, the point of which during the motion of the clamp may pass over a scale engraved upon a frame supported by the upper clamp. The frame bears upon one arm a scale graduated to millimetres, and upon the other arm a scale graduated to one-fiftieth of an inch. The end of the pendulum, or lever, may move over a scale upon an arc graduated to grammes and fractions of grammes by experiment. To test the strength and elasticity of a fibre it is fixed in the clamps, which are exactly 20 millimetres apart. By means of the screw motion strain is very gradually applied, and the pendulum moves from the vertical and furnishes the resistance. As the strain increases the fibre stretches, the clamps become more widely separated, and the degree of separation is measured by movement of the indicator attached to the lower clamp over the scale upon the frame attached to the upper one. To secure a fair average for wool 30 fibres must thus be tested from each sample.

Now the determination of the ultimate strength and elasticity may be made in two ways. First, and in order to record the true elasticity, a certain strain is applied, say sufficient to produce elongation of one millimetre. The strain is then relieved, and the fibre allowed to regain as far as possible its original length. When the contraction appears to be complete the strain is applied, and the total stretch and the permanent stretch are recorded. Strain is again applied until stretch of two millimetres is produced, when it is relieved and the contraction observed. Such experiment is repeated until rupture is effected. In the record, therefore, we have strain, total stretch, and permanent stretch or set. It is plain that the difference between the total stretch and permanent stretch or set represents what we ordinarily understand to be elasticity.

Second.—Since the relation between the total stretch and the elasticity is so close, the former may be accepted as fairly representing the latter quality in comparison of a large number of samples. The very much quicker method of testing may then be used, that is, to apply the strain gradually and continuously until rupture is effected, observing and recording the strain and total stretch.

An illustration of the tests made by the first method, and the mode of recording them for a single sample, is illustrated in the following, giving the results for 10 fibres of Cotswold wool having an average diameter of 4.412 centimillimetres.

Strain.....	Total stretch...	Permanent stretch...	Strain.....	Total stretch...	Permanent stretch...	Strain.....	Total stretch...	Permanent stretch...
Fibre No. 1.			*Fibre No. 6.*			*Fibre No. 11.*		
17.50	1.00	0.25	11.75	1.00	0.25	22.00	1.00	0.25
20.00	2.00	0.75	14.50	2.00	0.75	26.00	2.00	0.75
21.25	3.00	1.00	16.00	3.00	1.00	27.50	3.00	1.25
22.50	4.00	1.75	16.50	4.00	1.75	28.75	4.00	1.75
23.75	5.00	2.25	17.75	5.00	2.25	30.00	5.00	2.25
26.50	6.00	3.00	20.50	6.00	3.00	34.50	6.00	3.25
30.50	7.00	3.75	21.75	6.25	.....	38.50	6.75	.....
Fibre No. 2.			*Fibre No. 7.*			*Fibre No. 12.*		
14.50	1.00	0.25	20.50	1.00	0.25	21.75	1.00	0.25
17.50	2.00	0.75	21.75	2.00	0.75	24.50	2.00	0.75
18.25	3.00	1.25	22.50	3.00	1.00	25.75	3.00	1.25
18.75	4.00	1.75	23.50	4.00	1.75	27.25	4.00	1.75
19.75	5.00	2.25	25.25	5.00	2.25	29.25	5.00	2.50
21.50	6.00	3.00	28.25	6.00	3.00	33.25	6.00	3.25
22.75	6.50	.....	33.50	7.00	3.75	36.75	6.75	.....
.....	.....	.....	37.50	7.75	.....	.....	.....	.....
Fibre No. 3.			*Fibre No. 8.*			*Fibre No. 13.*		
18.75	1.00	0.25	15.25	1.00	0.25	19.50	1.00	0.25
20.75	2.00	0.75	16.50	2.00	0.75	22.50	2.00	0.75
22.00	3.00	1.25	17.25	3.00	1.00	24.50	3.00	1.25
23.50	4.00	1.75	18.00	4.00	1.75	24.25	4.00	1.75
24.75	5.00	2.25	19.50	5.00	2.25	26.75	5.00	2.50
27.50	6.00	3.00	22.75	5.75	.....	29.75	6.00	3.25
31.75	7.00	4.00	.....	.....	.....	32.75	6.50	.....
Fibre No. 4.			*Fibre No. 9.*			*Fibre No. 14.*		
17.50	1.00	0.25	20.75	1.00	0.25	13.75	1.00	0.25
20.00	2.00	0.75	22.50	2.00	0.75	17.25	2.00	0.75
20.50	3.00	1.00	24.50	3.00	1.25	19.25	3.00	1.25
21.50	4.00	1.75	26.00	4.00	2.00	20.50	4.00	2.00
22.50	5.00	2.25	27.50	5.00	2.50	21.50	5.00	.....
25.00	6.00	3.00	30.25	6.00	3.00	.....	.....	.....
29.25	7.00	3.75	35.50	7.00	4.00	.....	.....	.....
31.50	7.50	.....	37.25	7.75	.....	.....	.....	.....
Fibre No. 5.			*Fibre No. 10.*			*Fibre No. 15.*		
16.00	1.00	0.25	10.25	1.00	0.25	21.00	1.00	0.25
18.75	2.00	1.00	12.50	2.00	0.75	24.50	2.00	0.75
20.75	3.00	1.25	13.50	3.00	1.25	26.25	3.00	1.00
22.50	4.00	1.75	14.50	4.00	1.75	27.50	4.00	1.75
23.50	5.00	2.25	14.50	5.00	2.50	28.75	5.00	2.50
25.75	6.00	3.00	15.75	6.00	3.25	33.00	6.00	3.25
29.75	7.00	.....	.....	.....	.....	36.75	6.75	.....

The results obtained in a series of tests by this method were tabulated and reduced by my friend and colleague Prof. N. Clifford Ricker, so that the samples of wools of any breed could be compared not only with each other but with wools from other breeds, or even with different kinds of material as well. In this work all the results of this series of tests were specially tabulated, and from them curves were plotted, the idea being to secure averages corresponding with the several units employed. Thus first it was necessary for each sample to determine for the purposes of the comparasons the average tensile strains required to produce in permanent stretch, in even and half millimetres, from one-half millimetre to the maximum produced, while for the total stretch they were computed for each successive millimetre. For each sample tests of ten fibres were taken, and the averages secured in this way for the sample above represented, 189 Cotswold, are the following,—stretch in millimetres, strain in grammes:

For permanent stretch:

Stretch	0.25	0.50	1.00	1.50	2.00	2.50	3.00	3.50	4.00
Average strains	19.58	20.81	22.96	24.25	25.36	26.76	28.89	31.84	33.05

For total stretch:

Stretch	1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00
Average strains	19.58	21.13	25.55	24.83	26.20	29.38	33.86	38.28

To determine averages for each breed represented the averages obtained above were collected for ten samples, and corresponding reductions made. But in order to compare results for different samples and secure averages for a class or breed, the fibres must be theoretically reduced to a common diameter, which for convenience was assumed for the material under examination to be four centimillimetres. Any other diameter could equally well be assumed. For reduction of all fibres to this uniform diameter Prof. Ricker made use of the following proportion and formula:

$$D^2 : 4^2 : : S : S^1$$

$$\text{or,} \quad S^1 = S \frac{16}{D^2}$$

In which:

4 = the assumed common diameter of the fibre.

D = the actual diameter of fibre for the given sample.

S = the actual tensile strain on the fibre in grammes, producing a certain elongation, total or permanent.

S^1 = the tensile strain in grammes that should be required to produce identical elongation in a fibre 4 centimillimetres in diameter.

The strains must be to each other as the squares of the diameters of the fibres, supposing the section to be of similar form.

Now if the average diameter of the sample under consideration be substituted for D in the formula, and the decimal value of $^{16}/_{D^2}$ be found, it will of course be a constant for that sample. Multiplying the observed strains for the sample by this decimal, we obtain strains corresponding with a diameter of 4 centimillimetres. Then by tabulating, etc., as before, the averages are completed. Comparing in this way the averages of samples from different parts of a single fleece, the following conclusions were arrived at.

1. Fibres taken from the shoulder having common diameter and equal weight are considerably stronger than the average for the fleece.

2. The shoulder is therefore the most valuable part of the fleece by weight.

3. The relative economic values of the different parts are as follows, from greatest to least: shoulder, side, hip, belly.

4. Fibres taken from the side closely approximate the average for the entire fleece.

5. The belly is much the least valuable part of the fleece.

Of course these deductions may be modified by applying the same method to a large number of fleeces belonging to different breeds or even of the same breed, as the general results given in another part of this paper will show. Modifications due to age and sex of the animal represented would doubtless also occur. With all the results we already have, further tests must therefore be made with a sufficient number of samples of the same kind to definitely determine the relations here shown. In fact, more extended results determined and represented in a slightly different way do show that this relation varies decidedly in different sexes of the same breed, for while in ram's wool the order ranges hip, shoulder, side, in the ewe's wool it ranges hip, side, shoulder. These conclusions cannot therefore be accepted as absolute for this breed, nor for wool in general, but they are of interest as illustrating the application of the method to the sample in question.

Applying the same method to the results for the five different breeds the wools of which were made the special subject of study, averages were obtained which led to the following conclusions:

1. Southdown wool is much stronger than that of any other of the breeds considered.

2. It is consequently more valuable, pound for pound for manufacturing purposes, where only the weight of the goods is to be taken into account.

3. And if the manufactured goods are made of the same weight, those composed of Southdown wool should be much stronger and more durable for the same cost.

4. If all are to be of equal strength the Southdown fabrics will be considerably lighter and cheaper than others, allowing greater profit provided the wool is produced at the same price per pound.

5. Cotswold wool is the weakest, requiring more weight for equal strength.

6. From these averages the wools of the five breeds rank in economical value as follows, from greatest to least: Southdown, Oxforddown, Merino, Lincoln, Cotswold.

7. In point of strength, Merino wool closely approximates the average value for the five breeds considered. Its economic value would therefore be a mean between those of the Southdown and Cotswold.

Comparing the relations between the total, permanent and elastic stretch produced by various strains, we reach the following conclusions:

1. The permanent stretch increases nearly as fast as the total stretch.
2. The elastic stretch increases about half as fast as the total.
3. Consequently the elastic stretch only changes about half as fast as the permanent stretch.
4. The permanent and elastic stretch are equal, as an average, when the total stretch equals about 4.3 millimetres or 21.5 per cent. of the original length of the fibre.

To better comprehend the significance of these values we may compare them with similar values for other materials the strengths of which have been determined. We may thus compare it with wood, ivory, whalebone, the metals, iron and steel, but to render this comparison more readily intelligible it becomes necessary to change the average tensile strains in grammes on fibres of wool 4 centimillimetres in diameter to corresponding strains in pounds per square inch of section of fibre. This may be done as follows:

The common diameter of fibre being 4 centimillimetres, the area of right cross section is 12.5664 square centimillimetres. One gramme on a fibre having this area of cross section corresponds to $\frac{1}{12.5664}$ grammes per square millimetre of section, or $\frac{10 \text{ kelogrammes}}{12.5664}$ 0.795773 kelogramme per square millimetre of cross section of fibre.

One kelogramme per square millimetre of cross section corresponds to 1422.308 pounds per square inch of section (Thurston, Materials of Engineering, I. 308). Consequently one gramme of tensile strain on a fibre 4 centimillimetres in diameter exactly equals a strain of 0.795773+1422.308=1131.834 pounds per square inch of section. Therefore if all the general average tensile strains for wool already found be multiplied by this coefficient we shall obtain their corresponding values in pounds per square inch. As this multiplier is a constant, it does not affect the relative values of the different kinds of wool at all. The results of this reduction are as follows: the permanent and total stretch given in millimetres, and the respective corresponding relative resistance or strains in pounds per square inch of section.

Permanent stretch	0.25	0.50	1.00	1.50	2.00	2.50	3.00	3.50	4.00	4.50	5.00
Resistance	21.720	22.659	24.527	25.805	26.667	27.911	29.416	32.639	35.065	36.024	41.300

Total stretch	1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00
Resistance	21.233	24.018	25.465	26.723	38.285	31.024	34.736	34 804

Since in the tests of wool made the length of fibre used was 20 millimetres, if the results for stretch be multiplied by 5 we obtain expression in per cents. of length which is more convenient for comparison with other materials. If the figures thus obtained and those just given are compared with corresponding values for wrought iron, cast iron and steel made by the United States Testing Board, published in Thurston's Materials of Engineering, Vol. II, pp., 351, 352 and 398, the following conclusions are reached:

1. The tensile strain for wool is about one-half that required to produce the same per cent. of total stretch in a wrought iron bar of equal cross section.

2. A permanent set commences in wool at about 59 per cent. of the amount of strain required to originate a set in a wrought iron bar, or at about 37 per cent. of the ultimate tenacity of wrought iron of good quality.

3. For steel the corresponding value is 34 per cent.

4. The ultimate average tenacity of wool appears to be nearly double that of average cast iron of equal cross section, about four-fifths that of good wrought iron and a little more than one third that of good steel.

5. The maximum stretch of wool is much greater than that of either metal, being 1.75 times that of wrought iron, 12.8 that of cast iron and 4.5 times that of steel.

6. The permanent stretch or set of wool appears to commence only when the total stretch equals nearly 5 per cent. of the original length of the fibres, which is at least ten times greater than the corresponding value for either metal.

7. Wool has more than twice the strength of toughest wood; 1½ times that of bone; 4 times that of white pine; 2.7 times that of whalebone; and nearly twice as much as soft brass wire, phosphor bronze, annealed iron wire or steel wire rope.

The comparative values of wool may farther be expressed, and very conveniently, in the *moduli* of *elasticity* which may readily be determined from the data above given. The term *modulus* of *elasticity*, much employed in the discussion of the resistance of materials, may be defined in either of two ways:

a. It is the ratio between the elongation of a bar of any material (whose section is a square unit and its length a linear unit of similar denomination) and the tensile strain producing that elongation. Its numerical value equalling the quotient of the strain by the elongation. The length of the bar is usually one inch, its section a square inch, and the strain is taken in pounds,

b. It is the tensile strain in pounds which would theoretically stretch a bar of one square inch section to just twice its original length, neglecting the reduction of section which occurs.

The definition first given is that most frequently employed and is the one here intended.

The formula for calculation of the modulus of elasticity is

$$E = \frac{1131.834\ S}{\frac{5\ E}{100}} = 22687\ \frac{S}{E}$$

in which:

E = the required modulus of elasticity.

S = the tensile strain on a fibre of wool 4 centimillimetres diameter.

1131.834 S = strain or fibre in pounds per square inch.

E = corresponding total elongation in millimetres. Since the length of fibre tested is 20 millimetres we have 5 E = per cent. of stretch placing the original length of fibre at 100—.

Applying the above formula to the average strains corresponding to the different elongations of fibre for wool of different breeds, we obtain the values of modulus of elasticity given in the following table. Since the numerical value of the modulus of elasticity evidently increases directly as the amount of strain required to produce a certain elongation of fibre, it follows that the most resistant fibres will have the greater modulus. The following are the values in question:

Stretch	1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00	9.00
Oxford	486689	269263	186419	144592	121106	109259	105948	101700	95904
Lincoln	372374	200335	139367	108826	92131	84774	81686	81351	.....
Southdown	523813	310892	223319	173850	147637	134154	128512	.....	.....
Merino	395257	233250	169775	138819	118616	109486	100992	91537	.....
Cotswold	345662	186755	130236	101865	86155	78700	75801	73313	.....
Average	424661	240175	169775	133613	113138	103412	99246	87010	.....

From the above it appears:

1. The modulus of elasticity for Merino wool is pretty nearly the average for the five breeds considered.

2. The value of the modulus diminishes very rapidly as the stretch increases, the relative values for the general average being as follows:

Stretch per cent	5	10	15	20	25	30	35	40
Value of modulus	100	57	40	32	27	24	24	21

3. The relative numerical values of the modulus for the different breeds are arranged in the following order from the greatest to the least: Southdown, Oxforddown, Merino, Lincoln, Cotswold.

Comparing these values of moduli of elasticity of wool with similar values for wrought iron, cast iron, steel, wood and other materials computed from data already referred to ("Thurston, Materials of Engineering" II, 351, 352, 398) by dividing elongation per inch of length by corresponding strain in pounds per inch of cross section, we arrive at the following conclusions:

1. The values of the moduli of elasticity for the average of wool are much smaller than for either of the metals examined, but remain much more nearly uniform under increase of stretch and strain.

2. If the maximum value of the modulus of elasticity for the average of wool be taken as unity, the relative values for other materials will be as follows: White pine 4; strongest woods 4; silk 3; brass wire 34; phosphor bronze 33; copper wire 40; cast iron, average 37; wrought iron, average 59; steel, average 67.

This relatively low value of the modulus of elasticity for wool does not affect its tensile strength, as it results from the much greater stretch produced in wool by the same strain than in almost any other material, but it only permits it to stretch more and with a smaller proportional permanent stretch than other materials, thus rendering it much better adapted to the manufacture of clothing, etc., than if the modulus were several times greater or the stretch smaller.

In the consideration of these relations developed by Professor Ricker, it must be borne in mind that they are based upon the results of a small number of tests, and that they must suffer some modification when the same methods are applied to the results of more extensive work. We have here presented only a brief abstract of the methods and results, and for further information must refer to the detailed report upon "Examination of Wools, etc.," published by the U. S. Department of Agriculture.

In a very much more extended series of experiments, and with much more material, the second method of testing was used, that is, to apply the strain gradually and continuously until rupture was effected, observing and recording the strain and total stretch. We have already seen that the stretch taken in this way may fairly be accepted as representing the elasticity because of the very close and uniform relation existing between the total stretch and the elastic stretch, and though the percentage of stretch may diminish with increase of length of fibre tested, and some difference also prevail between the total and elastic stretch, yet if the same length to be tested be used in all experiments, the results must after all be comparable and thus satisfy the needs of the investigation.

We have further seen that in order to properly compare different wools with each other, the observed strains must be reduced to theoretical strains for fibres of assumed common diameter or common area of cross section, and determine the relation between these strains and the total stretch as expressed in the modulus of elasticity. And when so many tests are to be considered as were made in the portion of our work now under discussion, the calculation needs to be somewhat simplified, and formulæ slightly different from those already given, or at least a combination of some of them in a single formula becomes necessary.

The determination of the theoretical strain for the common diameter of 4 centimillimetres, involves the use of the formula already given. $S^1 = S^{16}_{D^2}$

The *ultimate tensile resistance*, expressed in pounds per square inch of cross section, may be obtained from the observed averages of fineness or diameters and strains, by formula deduced in the following manner:

Assuming, of course, cylindrical form of the fibres,

Let S = the average ultimate tensile resistance (strain) in grammes for the specimens or classes tested.

Let D = the average diameter of fibre for the specimen or class, in centimillimetres.

When the area of cross section of the fibre in square centimillimetres will become $\frac{\pi \ D^2}{4}$

In a square millimetre there are $100 \times 100 = 10{,}000$ square centimillimetres. Hence 1 gramme per square centimillemetre = 10,000 grammes = 10 kilogrammes per square millimetre, and since 1 kilogramme per square millimeter = 1422.30786 pounds per square inch, 1 gramme per square centimillimetre = 14222.0786 pounds per square inch of section of fibre. Applying these values in the above formula, we obtain the expression for the ultimate tensile resistance in pounds per square inch.

$$R = \frac{4\ S + 14223}{\pi\ D^2}$$

Or

$$R = 18109 \frac{S}{D^2}$$

The practical application of this formula is as follows: Take the average results for fineness of strain for the Cotswold breed, 4.196 centimillimetres and 30.44 grammes respectively.

Then

$$\frac{18109 + 30.44}{(4.196)^2} = 31272 \text{ lbs.}$$

The same formula may be applied to any fibre, sample or class of samples for which we have the average diameter and the average ultimate resistance or strain required for rupture. The results of such calculations furnish data upon which to base absolute comparisons of the strength of the fibre in the different classes.

The *modulus of elasticity*, or the ratio of the stretch to the strain required to produce it, is determined in the same way as before. That is, we divide the corresponding average tensile resistance $(=18109 \ \frac{S}{D^2})$ in pounds per square inch by the percentage of stretch suffered previous to rupture. Then if the resistance be represented by R and the percentage of stretch by P, and the modulus of elasticity by E, the formula becomes

$$E = \frac{R}{P}$$

Applying this formula to the figures for Cotswold wool above obtained we have

$$E = \frac{31272}{.3545} = 88214.$$

For a given percentage of stretch, the modulus of elasticity will increase with increase of ultimate resistance, and conversely for a given ultimate resistance it will decrease with an increase in the percentage of stretch. The greater the ultimate resistance required to produce a given stretch in the fibre, the greater must be the modulus of elasticity. Hence we have here an expression for the ultimate economic value of the staple that will admit of almost absolute comparison between wools of the same kind at least, and even to a large extent between all kinds, or between wool and other materials. If we arrange the wools of the breeds we have studied in the order of their moduli of elasticity from highest to lowest, they range as follows:

Breed.	Modulus of elasticity.
Southdown	114315
Merino	102100
Leicester	101681
Lincoln	95636
Cotswold	88214
Oxforddown	87630

A Cotswold-Merino cross examined has a modulus of elasticity of 109953.

The following table will illustrate the method of collecting all the general averages to show the relations between the results of the tests, and the breed, sex, and portion of fleece from which the sample was taken. At the top of this table we present these general averages for the several breeds studied, and for *all* samples examined. Below this we present the averages for Merino wool, showing relation between sex and portion of fleece, and the qualities and data represented.

Averages of all Results for each Breed.

Breed.	No. of samples tested.	Length of fibre—inches.	Fineness.		Strain—grams.	Stretch—per cent.	$\frac{D^2 \times S}{D^2}$	$18100 - \frac{S}{D^2} = R$	$E = \frac{R}{P}$
			Centimillimetres.	Th'sandths of inch.					
Cotswold	109	5.156	4.196	1.6519	30.44	35.45	27.663	31.272	88.214
Leicester	1	9.75	3.879	1.5271	28.70	28.05	25.201	28.522	101.681
Lincoln	36	3.785	3.707	1.4594	25.66	35.35	29.876	33.807	95.636
Southdown	46	1.351	2.936	1.1559	12.78	22.95	23.181	26.286	114.315
Hampshire	2	2.188	3.298	1.2984					
Oxford	30	2.647	4.365	1.7185	30.43	33.05	25.554	28.918	87.630
Merino	204	1.502	2.131	0.8389	7.35	28.70	25.897	29.302	102.100

Averages of all Results for each Sex and Portion of Fleece of Merino Wools.

Sex and Portion of Wool.	No. of samples tested.	Length of fibre—inches.	Fineness.		Strain—grams.	Stretch—per cent.	$\frac{D^2 \times S}{D^2}$	$\frac{S}{1809 - D^2} = R$	$\frac{R}{E} = P$
			Centimillimeters.	Thousandths of inch.					
Rams.									
Whole fleece	85	1.424	2.215	0.872	7.12	25.30	23.219	26.281	103.071
Neck	17	1.4375	2.614	0.041					
Shoulder	17	1.338	2.171	0.854	6.73	26.85	22.847	25.862	96.320
Side	17	1.281	2.156	0.848	6.29	29.15	21.65	24.503	84.061
Hip	17	1.276	2.297	0.904	8.83	21.87	26.777	30.310	139.613
Belly	17	1.284	2.234	0.188					
Ewes.									
Whole fleece	90	1.491	2.084	0.820	6.42	26.05	23.651	26.767	102.753
Neck	18	1.3125	2.287	0.900	8.59	26.15	26.277	29.744	133.743
Shoulder	18	1.393	2.041	0.803	6.16	27.20	23.666	26.790	98.492
Side	18	1.368	2.054	0.808	5.78	30.80	21.920	24.787	80.476
Hip	18	1.219	2.206	0.868	7.92	22.30	26.039	29.881	133.690
Belly	18	1.306	2.160	0.850					

This table shows, among other things, what we have already observed, that in point of ultimate value as represented in the modulus of elasticity, the Southdown wool takes the lead, and that this is followed by the Merino. These two kinds of wool are most valuable for clothing. Extending the same comparison to the sexes in the Merino race, and the portion of the fleece represented, we find the ram's wool slightly better than the ewe's wool, and as a rule the hip wool better than that from the side and shoulder. On the other hand the highest quality as regards power to resist wear and represented in the modulus of elasticity, does not seem to be consistent with fineness. The coarser wools appear better.

We shall not attempt to present results showing the relation of the results in the different classes to the ages of the animals represented, and in this particular, as in a host of others, we must refer readers to the detailed report already referred to. In connection with the age it will suffice to say that for lamb's wool the modulus of elasticity is almost always high, but in the fully developed animal there seems to be an increase in value with increase of age until a maximum is reached, after which the quality declines. In the Cotswold and Lincoln this arrives at the age of 1 year; in the Southdown at 3 years, and in the Merino at about 4 years.

In the following table are the results of the extension of the above described methods of investigation and reduction to wools of the commercial grades of the markets of Boston and Philadelphia, and to similar series adopted as the standard for the grades of Germany. The lengths of fibre given here are necessarily greater than those given for the wools heretofore described, from the fact that the latter were mostly taken from the bodies of the animals on exhibition in September, and therefore had only about five months' growth. The lengths are all taken in crimp and without stretching the locks.

The relation between the closeness of the crimp and the fineness of the fibre is here apparent, and though there is some variation, it still appears to afford a tolerably fair indication of the fineness, at least the best at hand when a good microscope is not available. Further it appears from this table that the wools of the Boston market, as a whole, are somewhat longer and coarser than those of the Philadelphia market. The ultimate resistance in pounds per square inch and the modulus of elasticity seem to be higher in the Philadelphia grades than in the Boston grades, altogether indicating a generally better quality in the staple.

Comparing the American with the German grades, the Philadelphia grades seem about as fine and strong, the modulus of elasticity possibly a little lower. With the explanations already given, however, these comparisons may easily be made by those interested, and we therefore submit the tables without further comment.

Averages of all results for Commercial Grades.

BOSTON GRADES.

Grades.	No. of crimps per inch	Length of fibre in inches	Fineness. Centimillimetres.	Fineness. Thousandths of inch.	Strain in grammes	Stretch per ct.	$\frac{D^2 \times S}{D^2}$	$\frac{18109 \frac{S}{D^2} = R}{}$	$E = \frac{R}{P}$
Fine unwashed	20	2.335	2.162	0.8511	5.34	27.30	18,279	20088	75785
Fine from dead sheep	20	2.300	1.835	0.7224	4.33	32.10	20.575	23287	71873
Picklock	22	2.083	1.532	0.6031	2.15	32.85	14.656	16588	50495
XXX	22	2.063	1.567	0.6169	2.85	31.85	18.57	21006	65954
XX	20	2.250	1.870	0.7368	4.65	22.30	21.769	24639	110491
X	20	2.156	2.023	0.7964	5.50	28.80	21.502	24336	84500
Between X and No. 1	20	4.625	2.118	0.8338	3.92	14.85	13.981	15823	106550
No. 1	20	2.229	2.203	0.8673	5.72	12.60	18.858	23143	169391
No. 2	16	2.814	2.908	1.148	11.16	24.05	21.115	23898	99300
Delaine fine	20	3.375	2.084	0.8204	5.36	24.55	19.746	22343	91033
Delaine medium	14	3.375	2.533	0.9972	6.84	25.93	57.057	19305	74394
Combing fine	14	3.917	2.526	0.9944	8.26	21.45	20.713	23443	111837
Combing medium	10	4.781	2.626	1.0338	9.86	22.15	22.87	25884	116860
Combing coarse	....	6.125	3.420	1.3464	14.60	30.75	24.076	27249	88616
Common	....	31.875	3.431	1.3507	15.32	26.70	20.823	23568	88269
New Mexico	....	3.375	2.776	1.0889	13.49	24.00	28.212	32675	136148

PHILADELPHIA GRADES.

Picklock best	26	1.625	1.669	0.6570	3.00	30.75	17.232	19510	63418
Picklock fair	26	1.75	1.658	0.6527	4.60	31.50	26.78	33309	96222
Picklock medium	22	1.25	1.76	0.6929	4.67	27.10	24.122	27299	98442
Picklock low	22	2.00	1.435	0.5469	3.05	22.55	23.699	22533	118900
XXX good	26	2.00	1.687	0.6641	4.23	21.40	23.781	26914	125770
XXX extra	26	2.00	1.494	0.5889	3.44	27.60	24.658	27899	191080
XXX low	22	2.25	1.783	0.7019	5.06	25.65	25.466	28815	113343
XX good	22	2.50	1.655	0.6515	3.70	22.25	21.66	24504	110130
XX clothing	22	2.20	1.859	0.7318	5.03	25.25	23.235	26292	104126
XX low	20	2.00	1.736	0.6874	5.67	23.50	30.102	34067	144970
X good	20	2.00	1.835	0.7224	5.23	21.40	24.851	28126	131430
X fair	20	1.9375	1.932	0.7606	5.05	18.45	21.646	24492	132750
X low	20	2.125	1.911	0.7523	5.03	18.40	22.037	24934	135510
Delaine fine	20	2.50	1.924	0.9574	5.95	32.50	25.717	29110	89570
Delaine very fine	20	2.625	1.946	0.7661	7.22	29.25	30.505	34520	118020
X and above	22	2.00	2.133	0.8397	5.98	29.70	21.03	23802	80141
X and above	22	2.458	1.949	0.7673	4.86	34.20	20.47	23168	67743
X and above	20	2.025	1.983	0.7807	5.60	24.10	22.786	25773	106981
¼ blood good	14	2.75	2.404	0.9464	10.37	29.65	36.143	40904	141170
¼ combing	14	3.4375	2.383	0.9381	9.66	24.10	27.218	30808	127830
Combing, low	....	5.417	3.508	1.3810	20.79	30.50	27.03	30593	100300

Averages for Commercial Grades—Continued.

Grades.	No. of crimps per inch.	Length of fibre in inches.	Fineness. Centimillimeters.	Fineness. Thousandths of inch.	Strain in Grammes.	Stretch per ct.	$\frac{D^2 \times S}{D^2}$	$\frac{S}{18.109 D^2} = R$	$E = \frac{R}{P}$
⅞ blood good	14	2.594	2.573	1.0129	8.93	24.80	21.582	24424	98475
⅞ combing		2.75	2.563	1.0096	11.04	24.30	26.89	30424	125245
⅞ and ½ blood	10	2.958	2.513	0.9893	10.29	18.00	26.070	29506	163923
½ blood high	20	2.3125	1.791	0.7051	5.85	21.15	29.18	33026	156152
½ blood regular		1.8125	2.234	0.8795	6.56	18.95	21.031	38891	125890
Combing, washed	20	3.125	2.162	0.8511	6.25	23.30	21.394	24209	103900
⅝ blood	20	2.125	1.997	0.7862	4.96	21.30	19.899	22523	105740
Cotts		3.25	2.806	1.1047	20.07	32.35	40.784	46155	142619
Saxon, Imported	26	1.00	1.555	0.6043	2.73	18.25	18.538	20984	114980
Saxon, Domestic	26	1.125	1.328	0.5225	2.11	20.55	19.143	21663	105416

GERMAN GRADES.

Super Super Electa	34	1.125	1.923	0.7570	4.43	24.70	19.168	21697	87841
Super Super Electa	34	1.00	1.297	0.5499	2.89	18.05	26.632	30140	166981
Super Electa	30	1.75	1.655	0.6515	4.17	27.05	24.359	27571	101925
Super Electa	30	1.25	1.639	0.6452	3.65	22.40	21.739	24606	112146
I Electa	27	1.25	1.662	0.6543	3.45	22.15	19.984	22614	102093
I Electa	27	1.125	1.664	0.6551	4.03	21.45	23.287	26360	122890
II Electa	25	1.25	1.535	0.6043	3.70	26.60	25.125	28742	106926
II Electa	25	1.125	1.504	0.5921	3.22	19.20	22.777	25782	134285
I Prima	22	1.375	1.705	0.6712	4.43	23.60	24.383	27503	116922
I Prima	22	1.25	1.705	0.6712	3.85	23.80	21.19	23983	100769
II Prima	20	1.375	1.980	0.7511	4.13	27.70	16.855	19082	68889
II Prima	20	1.375	1.794	0.7062	3.96	30.25	19.687	22285	73671
Secunda	16	1.50	2.089	0.8224	5.06	21.20	18.553	20995	99033
Tertia	16	1.25	1.978	0.7787	4.82	24.75	19.711	22308	90133
Quarta	14	1.50	2.257	0.8885	6.28	22.30	19.725	22330	100137
High Pedigree Wool	20	1.25	1.953	0.7688	4.08	17.35	17.115	19376	111681
High Pedigree Wool	25	1.25	1.682	0.6621	3.51	24.10	19.85	22466	93222
Pure bred, Ancient Pedigree	22	1.875	1.894	0.7456	3.18	15.00	14.183	15684	104558
Impurely bred wool	25	1.25	1.661	0.6539	3.08	21.85	17.86	20214	92513
French Ram	16	3.50	2.136	0.8409	6.03	28.40	21.146	23938	84288
Rambouillet	20	3.125	2.120	0.8346	6.50	30.00	23.14	26190	87360
English Merino	16	1.625	1.615	0.6358	3.27	24.90	20.055	22693	91134
Australian Ewe	16	2.125	1.683	0.6625	3.35	21.65	18.924	21414	99910
Roger Ram (French)	20	4.125	2.365	0.9311	5.53	26.90	15.918	17905	66562
Rambouillet Ewe		1.00	2.487	0.9791	4.38	9.65	11.33	12823	13288
Rambouillet Ewe	16	4.00	2.196	0.8645	6.26	24.55	20.77	23496	95708

MISCELLANEOUS WOOLS.

In the investigation thus far described not enough of material was at hand to study satisfactorily the influence of the various wool growing sections and their climates, etc., upon the quality of the wool produced. And in order to supply this deficiency it was determined to collect from such sections reliable samples of Merino wool, from animals descended from the pure Vermont stock, of about two years of age, twenty samples being taken for each sex in each section. The samples were contributed by careful experts in sheep breeding, and are therefore believed to be the best obtainable. They came from Vermont, New York, Pennsylvania, Illinois, Wisconsin, Minnesota, Texas, and California. All were examined by the methods already described, giving results showing fineness, ultimate resistance and *modulus* of *elasticity*, the principal data upon which estimates of value must be based.

Further a careful study was made of a series of wools contributed by Messrs. Boechtel Brothers, of Willets, Mendocino county, California. These wools were taken from animals produced by the gentlemen named, in the application of a system of crossing the Merino with the Southdown and Shropshiredown breeds. The object of the examination was to determine the influence of this system of crossing, definitely carried out, upon the character of the staple.

The commercial result of this system of crossing is shown in the following table compiled from Messrs. Boechtel Brothers' records:

Fall and Spring	Number of days between fall and spring shearing.	Number of sheep shorn	Annual average of wool per head	Annual average selling price	Net return per head.	Average of Merino rams' fleeces	Number of wethers shorn annually	Annual average of Southdown fleeces.	Annual average 1st cross, ½ Merino ½ Southdown	Annual average 2d cross ¾ Merino ¼ Southdown	Annual average 3d cross ⅞ Merino ⅛ Southdown	Annual average 4th cross 15/16 Merino 1/16 Southdown	Annual average ⅝ Shropshire ⅜ Southdown ⅝ Merino	Annual average 9/16 Merino 7/16 Shropshire 9/16 Southdown	Annual average ¼ Merino ½ Shropshire ¼ Southdown	Annual per cent. of lambs
			Lb	Cts.	$	Lbs.	Lb	Lb	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	
1874–75	367	245	4.60	23 5/8	1 22	16 2/8	....	4.60	.....	.....	.....	.....	.....	.....	.....	60
1875–76	357	409	5.49	16.2	78	16.4	20	4.48	7.86	.....	.....	.....	.....	.....	.....	84
1876–77	366	519	6.19	23.5	1 28	17.4	76	4.49	7.57	.....	.....	.....	.....	.....	.....	97
1877–78	365	628	7.11	20	1 22	17	112	4.50	7.81	11.22	.....	.....	.....	.....	.....	70
1878–79	366	514	8.67	21.4	1 73	19.2	168	....	7.86	10.36	.....	.....	.....	.....	.....	90
1879–80	366	635	7.99	25.6	1 86	16.5	228	....	6.61	8.78	11.06	.....	.....	.....	.....	88
1880–81	373	551	8.74	26.4	2 04	15	115	....	6.31	9.12	8.75	.....	.....	.....	.....	75
1881–82	355	559	8.14	21.1	1 38	14	53	....	5.81	8.52	9.44	10.70	.....	.....	.....	55
1882–83	375	584	8.92	19 13/16	1 48	*13	....	....	6.75	8.88	10.05	10.97	9.14	.....	.....	90
1883–84	356	711	8.02	17 9/16	1 10	*14.1	....	....	5.72	8.22	.....	.....	8.27	9.44	8.63	80

* 7 Grade, 1 Merino.

The results here exhibited show the valuable influence of the Merino blood in increasing the weight of fleece in the down races, and it is believed that this system of crossing so intelligently carried out must produce eventually a race capable of producing at the same time large fleeces of good wool for the factory and large carcasses of good mutton for the shambles.

Again, an opportunity was afforded us to make comparison of the wools of the Negretti and the Saxon types, and of these wools with those from American Merinos. These foreign wools were represented by a lot of samples secured from a flock of Negrette sheep just imported to this country, and another lot of samples sent over by Herr Otto Steiger, a noted breeder of Saxon sheep.

It would be impossible here to enter into the details of the results obtained in these three branches of investigation, and we must be content with presenting only the conclusions arrived at from their consideration.

With regard to the Merino wools from different sections of the United States, then, we find:

1. Different fibres in any given sample may vary in diameter throughout their length from 5 to 15 per cent. of the average.

2. Fineness in American Merino wools may vary from 1 centimillimetre ($\frac{1}{2539}$ inch) to 4 centimillimetres ($\frac{1}{634}$ inch).

3. This variation as represented in the extremes is not affected either by the sex of the animal nor by the section. The average of the maxima will reach about 3.3 centimillimetres, and the minima about 1.2 for the American Merino wools generally.

4. The ultimate resistance of individual wool fibres of course depends greatly upon the diameter. But it appears that this will vary from a minimum of 1.5 grammes (say 23 grains) to a maximum of 15 grammes (230 grains).

5. The stretch the fibres will suffer previous to rupture also varies widely, from about 5 per cent., the length tested, to as high as 60 per cent.

6. There seems to be no special relation between the extremes for strain and stretch and the section in which the wool is grown, or the sex and age of the animal producing it. It must in all cases be referred to the individual.

7. With regard to the relation between the crimp of the fibre and the fineness, history repeats itself in this series, and while there is some connection between the two, and the averages of large numbers of samples show that the finer wools have as a rule the closer crimp, the indication is exceedingly unreliable from sample to sample.

8. Age seems to have an influence upon the fineness of the fibre. After the age of one year the wool appears to grow coarser with increase of years.

9. The total stretch the fibre is capable of sustaining previous to rupture seems to increase with advance of age, but the data are not fully definite with this regard.

10. Age has no perceptible influence upon either the ultimate resistance or the modulus of elasticity of the fibre.

11. In the averages of fineness the results are somewhat higher as a rule for the rams wool than for the ewes wool, showing the former to be the coarser.

12. If we arrange the sections represented with reference to the average fineness for all sexes and ages from lowest diameter to highest, they stand as follows:

	Average fineness in centi-millimetres.
Pennsylvania	1.687
Vermont	1.773
Texas	1.837
California	1.916
Illinois	1.926
Wisconsin	1.941
New York	2.034
Minnesota	2.042

13. If they be arranged with relation to fineness of both rams and ewes two years old, they will stand respectively:

Rams.	Average fineness in centimillimetre's.	Ewes	Average fineness in centimillimetre's.
Pennsylvania	1.48	Texas	1.75
California	1.821	Vermont	1.878
Illinois	1.92	California	1.897
Texas	1.933	Illinois	1.898
New York	1.955	Wisconsin	1.904
Vermont	2.06	Pennsylvania	1.91
Minnesota	2.079	Minnesota	2.005
Wisconsin	2.219	New York	2.098

14. If the sections be arranged with reference to the average fineness for both sexes two years old, they will stand in the following order from finest to coarsest:

	Average fineness in centi-millimetres.
Pennsylvania	1.711
Texas	1.837
California	1.883
Illinois	1.902
Vermont	1.979
New York	2.034
Minnesota	2.042
Wisconsin	2.048

15. The influence of density of the fleece upon all qualities is illustrated in the following table:

	Fineness—centimillimetres	Fineness—Thousandths of inch	Strain grammes	Stretch—per cent	$\frac{D^2 \times S}{D^2}$	$\frac{S}{1809 - D^2}$	$E = \frac{R}{P}$
Rams—							
Dense fleece	2.151	0.846	15.473	39.74	18.926	24421	72027
Open fleece	1.916	0.7543	4.378	42.965	19.086	21802	50280
Ewes—							
Dense fleece	2.119	0.8342	5.113	40.04	18.219	20621	50329
Open fleece	1.974	0.7771	4.581	37.345	18.81	21289	56099

This table shows:

a. That the finer fibre is found in the loose fleece both in ram's wool and ewe's wool.

b. That there is practically little difference in the ultimate tenacity of the fibre in the two kinds of fleeces, the tendency to the greater strength being in favor of the loose fleece.

c. The modulus of elasticity and hence the ultimate value of the wool is greater in the dense fleece than in the open fleece for ewe's wool, and *vice versa* for ram's wool.

d. The question of the influence of the density of the fleece upon the quality of the wool cannot be considered as fully settled by these results, but the tendency is strongly in favor of the open fleece.

16. Any special relation between the sex and the ultimate seems doubtful. In Vermont, Minnesota, Illinois and Texas, the ewe's wool is stronger, while in New York, Pennsylvania, Wisconsin and California the ram's wool takes precedence with this regard.

17. There appears to be a tendency to higher modulus of elasticity and consequently a higher ultimate value in ram's wool than in ewe's wool.

18. If we compare the moduli of elasticity of the wools of rams and ewes two years old for the several sections, we find them to range as follows from highest to lowest:

Rams.	Modulus of elasticity.	Ewes.	Modulus of elasticity.
Illinois	97962	Illinois	89998
Texas	93169	Texas	87677
Minnesota	70330	Vermont	86249
Vermont	68499	Minnesota	83690
California	67381	Pennsylvania	66226
Pennsylvania	64120	Wisconsin	66036
New York	58263	California	61520
Wisconsin	50361	New York	53936

19. If we compare the averages of the moduli of elasticity for both sexes two years old, we find the sections to stand in the following order:

	Modulus of elasticity.		Modulus of elasticity.
Illinois	91657	Pennsylvania	65275
Texas	90292	California	62600
Minnesota	77010	Wisconsin	58854
Vermont	74782	New York	55875

20. If we compare the average of the moduli of elasticity for all ages and sexes for the several sections, we find them to stand in the following order from highest to lowest:

	Modulus of elasticity.		Modulus of elasticity.
Illinois	91751	Pennsylvania	63795
Texas	90292	California	61972
Minnesota	77010	New York	55875
Vermont	70587	Wisconsin	48446

With regard to the cross-bred wools of Messrs. Baechtel Brothers, of California, the following, among other conclusions, have been deduced from the results:

1. The extremes of fineness vary from 1 centimillimetre ($\frac{1}{25\frac{1}{39}}$ inch) to 5 centimillimetres ($\frac{1}{5\frac{1}{08}}$ inch).

2. There is an apparent variation in the diameter of the same fibre of from 15 to 20 per cent. the average diameter.

3. There is great irregularity in the numbers occurring above and below the average of fineness, while a predominance of tests below the average frequently occurs.

4. We find in this series an exceptionally high extreme of stretch reaching 85 per cent. the length tested, while the minimum falls as low as 10 per cent. and even 5 per cent. the length tested.

5. In the averages of fineness for the several classes we find less variation than might be expected. Until the Merino blood falls as low as $\frac{1}{2}$ no influence of cross upon the fineness is discernible. And in no case does the variation in the average of fineness appear greater than might occur in animals of pure blood, until the Merino blood is reduced from $\frac{1}{4}$ to $\frac{3}{8}$.

6. With an increase of Shropshire blood there is a regular increase in the diameter of the fibre.

7. As might be expected, a comparatively wide margin occurs in the figures for all qualities, but all are, as a rule, high.

8. The average tensile resistance will vary from 15,000 to as high as 45,000 pounds per square inch of section, and the modulus of elasticity from 35,000 to 125,000. If we compare the general average as regards fineness, ultimate tensile resistance and moduli of elasticity, the grades stand as follows:

	Fineness centimillimetres.	Ultimate resistance pounds per square inch.	Modulus of elasticity.
Pure Merino	2.039	23289	76232
15/16 Merino, 1/16 Southdown	1.695	26032	77706
7/8 Merino, 1/8 Southdown	1.929	22997	106335
3/4 Merino, 1/4 Southdown	1.923	24911	61600
1/2 Merino, 1/2 Southdown	2.394	24051	58718
Shropshiredown	3.60	23038	59606
9/16 Merino, 4/16 Shropshire, 3/16 Southdown	2.122	22919	60141
3/8 Merino, 1/8 Shropshire, 1/8 Southdown	2.437	29774	74495
2/8 Merino, 1/8 Shropshire, 2/8 Southdown	2.358	22938	62500

9. If we compare this table with that of Messrs. Baechtel Brothers, we find that the highest value, as represented in the modulus of elasticity, corresponds with the highest net return for each animal.

10. The variations here noted are no greater than might occur from individual to individual.

11. For the production of medium wools the grade animals here described will yield as good a product as animals of pure blood.

12. These results, taken in connection with the similarity of structure of the fibres in the several breeds shown elsewhere, indicate the possibility of profitable results in the crosses between the down breeds and the Merinos.

13. If we arrange the moduli of elasticity in order from highest to lowest, we find the grade wools stand in the following order:

	Modulus of elasticity.
$\frac{7}{8}$ Merino, $\frac{1}{8}$ Southdown.	100335
$\frac{15}{16}$ Merino, $\frac{1}{16}$ Southdown.	77706
$\frac{3}{8}$ Merino, $\frac{4}{8}$ Shropshire, $\frac{1}{8}$ Southdown	74495
$\frac{2}{8}$ Merino, $\frac{4}{8}$ Shropshire, $\frac{1}{8}$ Southdown	62500
$\frac{3}{4}$ Merino, $\frac{1}{4}$ Southdown.	61600
$\frac{13}{16}$ Merino, $\frac{3}{16}$ Southdown, $\frac{3}{16}$ Southdown.	60441
$\frac{1}{2}$ Merino, $\frac{1}{2}$ Southdown.	58718

14. If we arrange the fineness from lowest average diameter in centimillimetres to highest, the several grades assume the following order:

$\frac{3}{4}$ Merino, $\frac{1}{4}$ Southdown.
$\frac{7}{8}$ Merino, $\frac{1}{8}$ Southdown.
$\frac{15}{16}$ Merino, $\frac{1}{16}$ Southdown.
$\frac{9}{16}$ Merino, $\frac{3}{16}$ Southdown, $\frac{4}{16}$ Shropshire.
$\frac{2}{8}$ Merino, $\frac{4}{8}$ Shropshire, $\frac{2}{8}$ Southdown.
$\frac{1}{2}$ Merino, $\frac{1}{2}$ Southdown.
$\frac{3}{8}$ Merino, $\frac{4}{16}$ Shropshire, $\frac{1}{8}$ Southdown.

Other conclusions may doubtless be drawn from these figures. Our object has been principally to simply develop here the true value of the material represented, leaving to others the matter of the practical application of the results; but we believe they offer very much of encouragement to those especially interested in the combination of mutton production with the production of moderately fine wool. Here is simply a beginning of what should be done. The variations in the ultimate value of the staple by the infusion of coarser wooled blood and even in the fineness, is so slight as to appear almost insignificant. The first cross appears to have a marked influence upon the quality of the fibre, but the later crosses appear to produce very nearly an equilibrium with this regard.

Consideration of the results of the tests of German wools developed the following conclusions:

1. In the Negretti wools there appears to be a decrease in diameter of the fibre, from the skin outward.

2. This variation is quite irregular, but may be as great as 20 per cent. of the entire diameter.

3. The larger number of the measurements appear to be below the average.

4. The Saxony wools appear to be finest at about the middle of their length, the variation being about the same as stated for Negretti wool.

5. In the Saxony wools the measurements above and below the average are about equally divided.

6. In the Negretti wools the actual strain varies from an extreme minimum of 1 gramme, (15.435 grains) to an extreme maximum of 11.50 grammes, (117.49 grains).

7. The averages of the extremes of fineness in Negretti wools, vary from a maximum of 2.695 centimillimetres ($\frac{1}{94}$ inch) to a minimum of 1.087 centimillimetres ($\frac{1}{164}$ inch). The averages vary from a maximum of 2.02 centimillimetres ($\frac{1}{127}$ inch) to a minimum of 1.546 centimillimetres ($\frac{1}{164}$ inch). The absolute extremes vary from a maximum of 3.25 centimillimetres ($\frac{1}{78}$ inch) to 0.875 centimillimetres ($\frac{1}{290}$ inch).

8. In the Saxony wools, the absolute extremes of fineness range from 1.00 centimillimetres ($\frac{1}{253}$ inch) to 3.375 centimillimetres ($\frac{1}{72}$ inch). The average extremes from 1.208 centimillimetres ($\frac{1}{120}$ inch) to 2.847 centimillimetres ($\frac{1}{80}$ inch) while the general average is 1.854 centimillitres ($\frac{1}{136}$ inch).

9. The stretch in Negretti wool varies from extremes of 5 to 40 per cent. the length tested, their averages being 7 to 30 per cent., the general average being 22 per cent. In the Saxony wool absolute extremes of stretch vary from 10 to 58 per cent. the length tested, the average extremes from 27 to 53, while the general average amounts to 40 per cent.

10. The ultimate resistance of Negretti wools varies from say 15,000 pounds per square inch to 32,000 pounds per square inch, with an average of 23,579. The averages of moduli of elasticity vary from 67,038 to 167,367, with a general average of 84,917.

11. The average ultimate resistance of the Saxony wools varies from 17,000 to 41,000 pounds per square inch of cross section, with a general average of 23,225 pounds. The averages of moduli of elasticity vary from 45,000 to 111,000, with a general average of 57,000.

12. Hence it appears that the Negretti wools, both as regards fineness and ultimate strength, are more valuable than the Saxony wools.

13. It also appears that they are, with one exception, finer than the Merino wools from the several sections of this country represented in the investigation here described. And as regards ultimate strength represented in modulus of elasticity, if entered in our tables of comparisons they would occupy the third place. If the Saxony wools were likewise entered in our comparison they would occupy the seventh place.

These are some of the conclusions to be drawn from the results of our extended study of wools of the United States. Many relations still remain to be developed, not only from these results, but from further experiment and investigation. The field entered upon was comparatively new, and there still remains much to be studied that will yield facts of the greatest scientific and practical value. In the results presented here, and in the detailed report already referred to, both breeders and manufacturers must be able to discover relations that naturally escape the investigator. In the ultimate resistance and moduli of elasticity taken by themselves or in

connection with the fineness, they have almost absolute standards of va ue. If these methods and the standards obtained by means of them were extended to actual working processes and material, manufacturers and breeders alike have nearly perfect means for the comparison of their products and exact determination of differences upon which important questions may turn. Control of the products of the woolen industry by this means may become as ready as control in the industry of iron and steel is by chemical analysis, and I firmly believe that its application by breeders of standard flocks, at least in making selections of breeding animals, will do much to improve the quality of our fine wools.

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